Troitsk Institute for Innovation and Fusion Research
Efremov Institute
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Optimization of QSPA-Be plasma gun facility for ITER ELM, disruption, and mitigated disruption simulation experiments. Preliminary results of Be erosion under ELM-like plasma heat loads.

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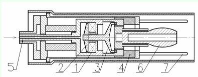
Introduction

The first wall PFCs erosion under ITER transient plasma events such as ELM, disruption and mitigated disruption is expected to determine the PFCs lifetime and amount of erosion products in a form of dust particles and films. The magnitude of ITER plasma and radiation heat loads during transient plasma events are not achieved in existing tokamaks so other devices are used for armour testing. The quasistationary plasma gun QSPA-Be facility provide the hydrogen (or deuterium) plasma heat loads corresponding to ITER ELM and disruption in the range of 0.2-5 MJ/m^2 and pulse duration 0.5 ms. Because of specific safety requirements QSPA-Be facility was installed in Bochvar Institute and was licensed to work with beryllium targets.

QSPA-Be facility

QSPA plasma gun design



1 – coil of pulse electromagnetic gas valve; 2 – valve disk; 3 – volume of pulse valve; 4 – isolator; 5 – gas supply tube; 6 – cathode; 7 – anode.

The QSPA-Be facility is powered by the low inductance capacitor bank. There are 480 capacitors in the bank. The bank consists of six equal sections.

Maximum working voltage of the capacitor bank:	U_{max} = 5 kV
Capacity of a section:	C = 8 μF
Maximum discharge current:	I_{max} = 300 кА

The main lines of the work

•Calibration of QSPA-Be which include the measurements of plasma velocity, pressure, and heat loads depend on operating parameters;

•Optimization of QSPA-Be power supply system to obtain power pulse form relevant to different transient plasma events of ITER;

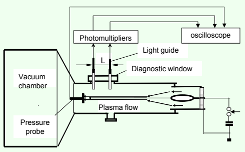
•Experimental study of plasma stream energy transformation to radiation for mitigated disruption simulation;

•Experimental study of beryllium erosion under ITER ELM-like plasma heat loads up to 1 MJ/m^2 and pulse duration 0,5 ms.

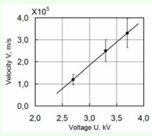
Calibration and optimization of QSPA-Be

Plasma pressure and plasma flow velocity

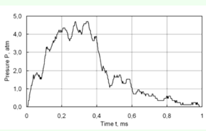
To measure the plasma pressure the pressure probe with sensitive element from CTS-19 ceramic was applied.



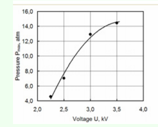
The pick value of the plasma flow velocity as a function of the gun voltage



The typical curve of pressure evolution for the QSPA-Be pulse



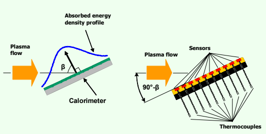
The pick value of the plasma pressure as a function of the gun voltage



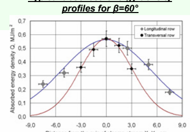
Absorbed energy density distribution

Special multi-channel two dimensional calorimeter was used for measuring of the absorbed energy density distribution.

The scheme of the calorimeter location



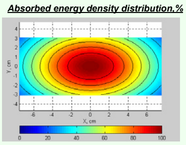
Typical absorbed energy density profiles for β=60°



$$Q(x,y) = Q_0 \cdot \exp\left(-\frac{x^2}{2\left(\frac{\sigma}{\cos(\beta)}\right)^2}\right) \cdot \exp\left(-\frac{y^2}{2\sigma^2}\right)$$

Q_0 – absorbed energy density at the flow axis
σ = 3±0.5cm – effective radius of the plasma flow
β – angle of incidence of the plasma flow to the target surface

Absorbed energy density distribution,%



2D distribution of the absorbed energy density are approximated well with Gaussian curve.

Optimization of QSPA-Be power supply system

Using the standard power supply system QSPA-Be facility generates plasma flows with duration 0.5 ms and the trapeziform discharge power pulse.

As a result of the investigation the parameters of the power supply system was determined to generate triangular discharge power pulse. The front of pulses may be varied in the range of 0.2-0.5 ms.

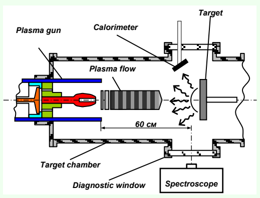
Radiation source for the mitigated disruption simulation

Experimental study of plasma flow energy transformation to radiation with the view of generating the radiation corresponding the ITER mitigated disruptions was carried out.

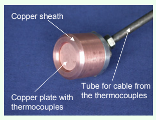
The experiments

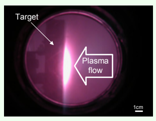
Working gas:	the mixture of hydrogen and argon
Target:	graphite plate (MPG-8)

The scheme of the experiments and diagnostics



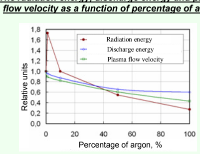
calorimeter





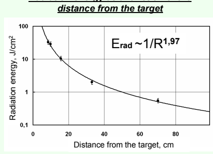
Results of the experiments

The radiation energy, discharge energy and plasma flow velocity as a function of percentage of argon



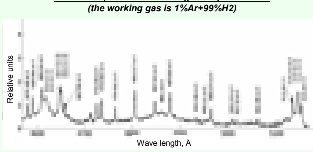
The maximum value of the radiation energy was obtained using the mixture 1%Ar+99%H_2 as the working gas.

Radiation energy as a function of the distance from the target



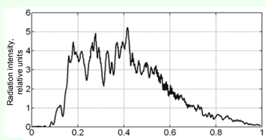
The maximum value of the radiation energy corresponding to the distance from the target 8,5cm and gun voltage 4kV is equal 90 J/cm^2.

Radiation spectrum of the stagnated plasma flow (the working gas is 1%Ar+99%H2)



Radiation spectrum has a line structure. The brightest lines correspond ions of argon, hydrogen and carbon.

Radiation intensity evolution of the stagnated plasma flow (the working gas is 1%Ar+99%H2)



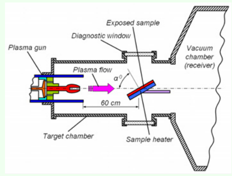
The radiation duration registered by means of photomultiplier coincides with the duration of the discharge current and is equal 0.5 ms.

This work was supported by the Impuls- und Vernetzungsfond der Hemholtz Gemeinschaft e.V. and RFBR grant Nr.11-02-91322

First beryllium experiments on QSPA-Be

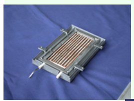
The different type of beryllium (TGP56-PS and S-65C) were exposed by hydrogen plasma flow in the heat loads range of 0.2-1MJ/m^2, 0.5 ms pulse duration and inclined plasma action.

Experimental conditions

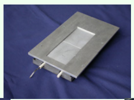


• Target temperature:	20^{o}C
• Plasma pulse duration:	0.5 ms
• Plasma-surface angle α:	60^0
• Total number of pulses:	60
• Absorbed energy density:	0.2÷1 MJ/m^2

Beryllium target

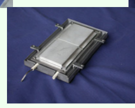


The heater with two beryllium samples



The common view of the ready-mounted beryllium target

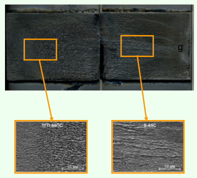
The heater that enable to heat the samples and maintain its temperature in the range of 0-600^{o}C



The heater with two beryllium samples and the beryllium frame

Results of the experiments

As a result of the beryllium target exposure by hydrogen plasma flow the melted region is observed on the samples surface. The formation melted region is caused by exceeding the head load over the melting threshold. Since the sizes of melted region and absorbed energy density distribution are known the melting threshold may be determine.

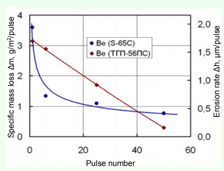


Experimental determined melting threshold for both type of beryllium samples is equal 0.5 MJ/m^2

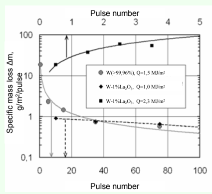
Beryllium erosion

The measurements of the samples mass were implemented after 10-40 pulses. On the basis of the measurements the average value of specific mass loss was calculated.

The specific mass loss value of different type of beryllium



The specific mass loss value of different type of tungsten obtained in the early experiments on QSPA-T.



▪The maximum mass loss is observed at first pulses and lies at level 3,5 g/m^2/pulse (erosion rate 1.8 μm/pulse).
▪The value of mass loss is decreased with increasing of number of pulses and already after 60 pulses lies at level 0.5 g/m^2/pulse (erosion rate 0.3 μm/pulse).
▪The beryllium mass loss mainly duo to the mass loss of the melt layer on the surface of samples.

Programme of beryllium researches

▪**Beryllium erosion under exposure to plasma flow**

▪**Beryllium erosion under exposure to radiation**

▪**Beryllium dust and films**

▪**Mixed materials (Be/W/C)**

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